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US Army Corps of Engineers

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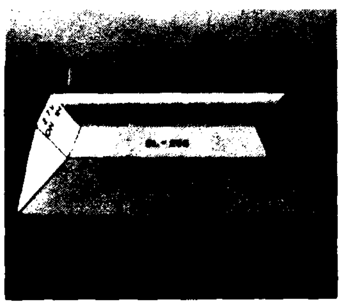

TECHNICAL REPORT HL-92-13

OLMSTED LOCK OUTLET, OHIO RIVER

Hydraulic Model Investigation

by

Richard L. Stockstill

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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November 1992

Final Report

HYDRAULICS LABORATORY

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Louisville, Kentucky 40201-0059

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13. ABSTRACT *(Maximum 200 words)*

The navigation locks at the proposed Olmsted project, Ohio River, will consist of two 110- by 1,200-ft locks having a design lift of 21 ft. The locks' filling and emptying system consists of culverts from the land wall, the river wall, and the middle wall emptying into a single outlet structure located in the river. The Olmsted Lock design is unique in that the four culverts from the two locks all terminate in a common outlet structure. Tests were conducted on a 1:25-scale model of the proposed Olmsted Lock outlet structure that reproduced 1,150 ft of the Ohio River beginning 650 ft upstream of the outlet and approximately 400 ft of the width of the river. This model was used to evaluate the performance of the outlet structure for the project. Observations of flow patterns in the vicinity of the outlet structure during emptying operations indicated that no adverse flow conditions resulted from the combining of the four culverts into one outlet structure.

(Continued)

14. SUBJECT TERMS

Discharge (water)	Ohio River
Hydraulic models	Olmsted Locks and Dam
Lock culverts	Outlets

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13. ABSTRACT (Continued).

Stability tests were conducted with the type 1 design riprap plan, which consisted of stones having a D_{50} of 20 in. placed from sta 30+46 to sta 35+66 and from the lock wall riverward 250 ft. With a river unit discharge of 130 cfs/ft and a tailwater elevation of 279 and with both locks discharging 10,500 cfs per lock for 5 hr (prototype), a few stones were displaced in an area about 15 to 25 ft riverward from the outlet structure. The type 2 design riprap plan (stones having a D_{50} of 24 in.) was found to be stable for these flow conditions and is recommended for the prototype.

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers, on 25 September 1991 at the request of the US Army Engineer District, Louisville. The model tests were accomplished during the period March 1992 to May 1992 by personnel of the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; and G. A. Pickering, Chief, Hydraulic Structures Division (HSD), HL. Tests were conducted by Messrs. V. E. Stewart, Sr., and R. L. Stockstill, Locks and Conduits Branch, HSD, under the supervision of Mr. J. F. George, Chief, Locks and Conduits Branch. This report was prepared by Mr. Stockstill and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

The model components were constructed and assembled by Messrs. M. A. Simmons, J. A. Lyons, and C. H. Hopkins, Engineering and Construction Services Division (E&CSD), WES, under the supervision of Mr. S. J. Leist, Chief of the Model Shop, E&CSD. Pipe work for the model was provided by Messrs. K. K. Raner, J. E. Townsend, and M. E. Anderson, E&CSD, under the supervision of J. Taylor, Chief of the Pipe Shop, E&CSD. General construction of the model was completed by F. James, H. R. Brown, K. R. Chiplin, V. J. Durman, W. Kelly, A. J. Lee, and E. C. Rhodman, under the supervision of C. Drayton, Model Construction Section, E&CSD.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms

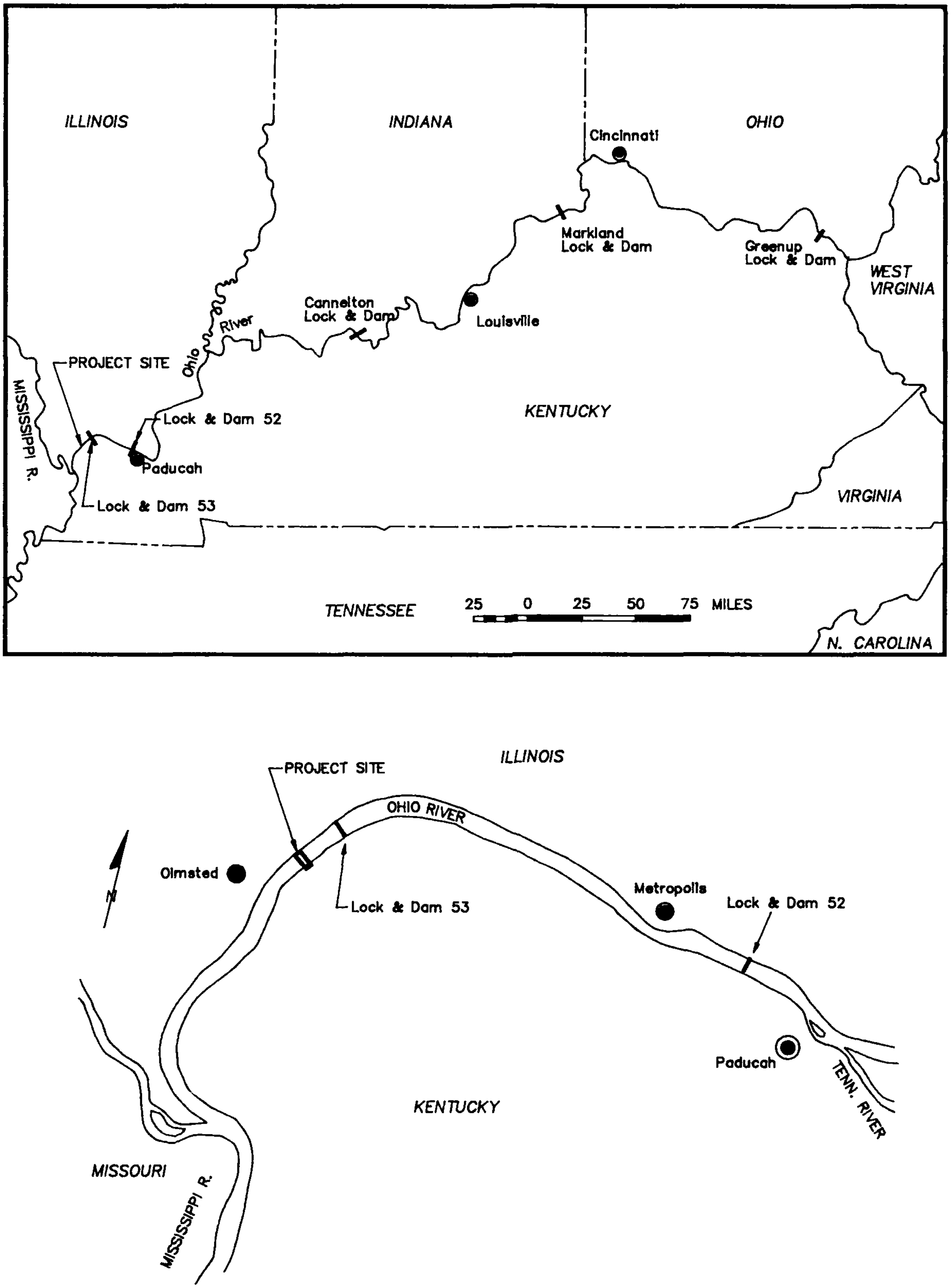

Figure 1. Vicinity and location maps

OLMSTED LOCK OUTLET, OHIO RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The US Congress authorized replacement of Locks and Dams 52 and 53 with a single structure located at the Olmsted Site under the Water Resources Development Act of 1988 (Public Law 100-676).* The project will be located at Ohio River Mile 964.4, 16.6 miles** upstream of the mouth of the Ohio River at Cairo, IL (Figure 1). The tailwater of the Olmsted Locks and Dam will not be controlled by a downstream navigation project, but will be influenced by Mississippi River stages. The proposed locks will consist of two 110- by 1,200-ft locks located on the Illinois side of the Ohio River. The locks will have a normal design lift of 21 ft (upper pool at el 300† to tailwater at el 279). The design of the locks' filling and emptying systems was based on the system used for the 1,200-ft lock at Cannelton Locks and Dam†† due to the similarities in water levels and structure dimensions of the locks. The culverts from the land wall, the river wall, and the middle wall will empty into a single outlet structure located in the river (Plates 1 and 2). The culvert from the land wall and middle wall will pass beneath the lock floor. The invert of the outlet structure is at el 235.

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* US Army Engineer District, Louisville. 1989 (Mar). "Olmsted Locks and Dams (Replacement of Locks and Dams 52 and 53)," General Design Memorandum, Design Memorandum No. 1, Main Report, Vol 1, Louisville, KY.

** A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

† All elevations (el) cited herein are in feet referred to the Ohio River Datum.

†† J. H. Ables and M. B. Boyd. 1966 (Feb). "Filling and Emptying System, Cannelton Main Lock, Ohio River, and Generalized Tests of Sidewall Port Systems for 110- by 1200-ft Locks; Hydraulic Model Investigation," Technical Report 2-713, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Purpose and Scope of Model Investigation

2. The Olmsted Lock design is unique in that the four culverts from the two locks all terminate in a common outlet structure. There was concern that the combining of all four culverts could result in adverse flow conditions in and near the outlet structure. The purpose of the model study was to document flow patterns during emptying from the land lock, the river lock, and both locks simultaneously, and make necessary structure modifications to the outlet structure if required. After the study was under way, it was decided that the stability of the proposed riprap plan should also be tested.

PART II: THE MODEL

Description

3. The 1:25-scale lock outlet model reproduced the lock emptying system downstream of the emptying valves, approximately 1,150 ft of the Ohio River beginning 650 ft upstream of the outlet, and approximately 400 ft of the width of the river (Figure 2). The river topography was molded in sand and cement mortar to sheet metal templates and was given a brushed finish. The culverts were constructed of transparent plastic, and the outlet bucket was constructed of plastic-coated plywood.

Appurtenances and Instrumentation

4. Water was supplied to the model through a circulating system. The riverflow was measured with a venturi meter installed in the inflow lines. The four emptying culverts were connected to a headbox containing a fixed skimming weir that maintained an essentially constant head on the emptying valves during emptying operations. Discharge through the emptying system was measured with a flowmeter installed in one of the four lines. Flow through the emptying culverts was controlled by slide gates in the culverts. The movement of the slide gates was controlled by servo-driven linear actuators that were regulated by a microcomputer. The microcomputer was programmed for varied output to reproduce the desired valve schedule. The slide gates were calibrated by measuring the discharge to gate opening relation for the fixed head provided by the weir. Calibration allowed the reproduction of the lock emptying hydrograph. The hydrographs were computed using the Conversationally Oriented Real-Time Programming System (CORPS), Program H5322.* An overall lock emptying coefficient of 0.745 and a 4-min valve operation for the design lift of 21 ft were used to compute the hydrographs. The hydrographs for normal and single-valve operations are shown in Plate 3.

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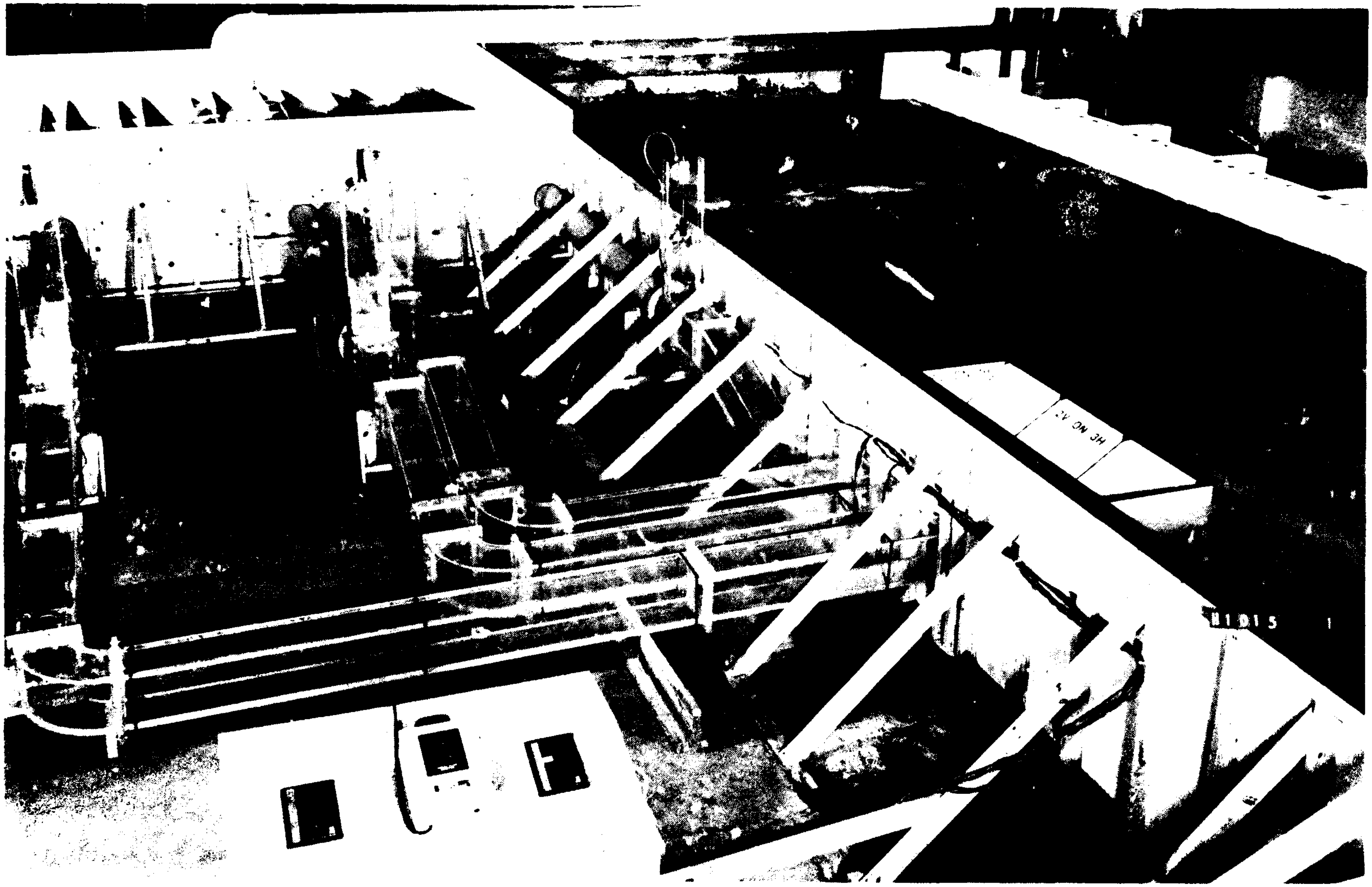
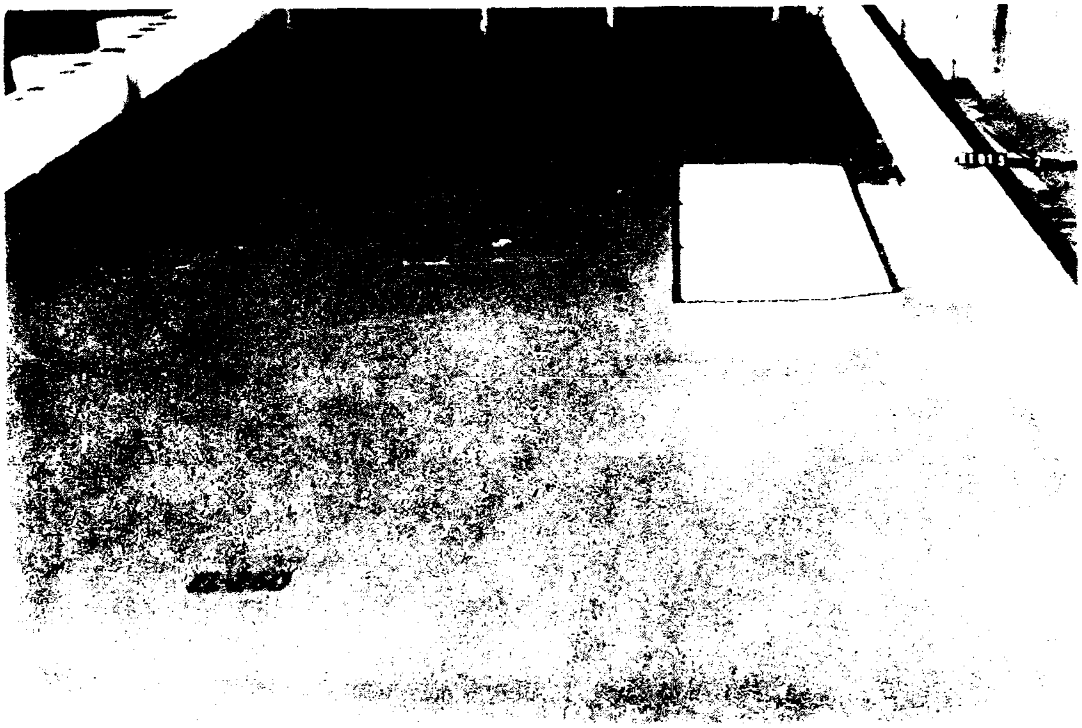
* Frank M. Neilson and Martin T. Hebler. 1988 (Apr). "H5322 - Revision of H5320 WRT Inertia, Hydraulic Friction, Value and Expression," Conversationally Oriented Real-Time Programming System (CORPS). Available from US Army Engineer Waterways Experiment Station, ATTN: CEWES-IM-MI-C, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

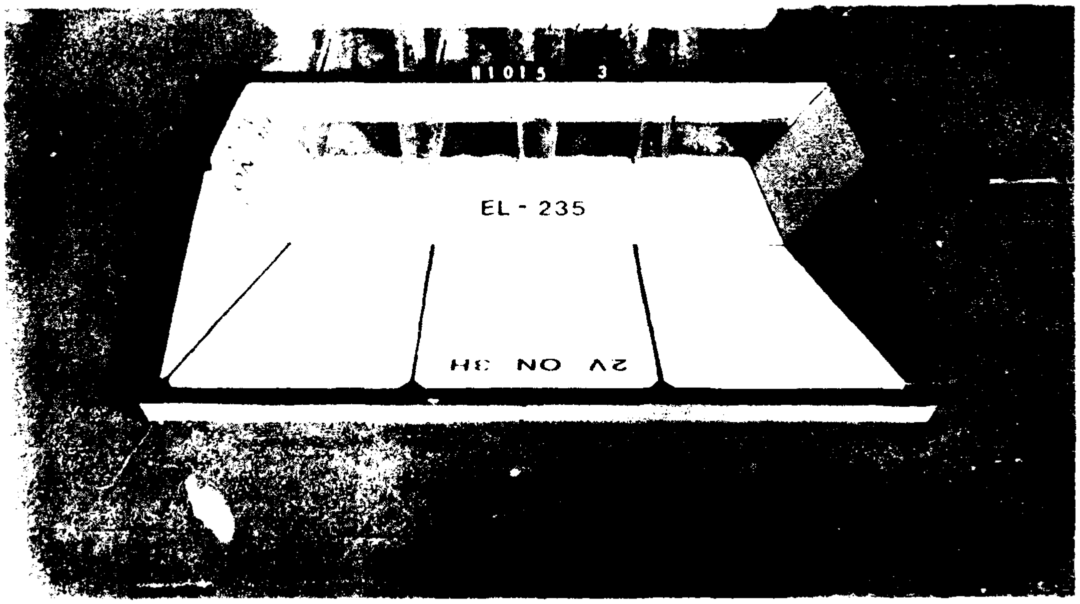


a. General view

Figure 2. The 1:25-scale model (Continued)



[illegible] view of outlet and river, looking downstream



Close-up view of outlet structure

Figure 2. (Concluded)

5. Dye and confetti were used to study subsurface and surface current directions. Velocities were measured with a commercial current meter that was mounted to permit measurement of flow from any direction and at any depth. Water-surface elevations were measured with point gages, and various flow conditions were recorded photographically.

Scale Relations

6. The accepted equations of hydraulic similitude, based on the Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transfer of the model data to prototype equivalents, or vice versa, are presented in the following tabulation. Because of the nature of the phenomena involved, certain model data can be accepted quantitatively, while other data are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and resistance to displacement of riprap material can be transferred quantitatively from model to prototype using the following scale relations.

Characteristic	Dimension*	Scale Relations Model:Prototype
Length	$L_r = L$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Volume	$V_r = L_r^3$	1:15,625
Weight	$W_r = L_r^3$	1:15,625
Time	$T_r = L_r^{1/2}$	1:5

* Dimension are in terms of length.

PART III: TESTS AND RESULTS

Outlet Structure

7. Velocities near the outlet structure were measured for steady-state flow conditions at a maximum outlet discharge of 10,500 cfs per lock, or 21,000 cfs when both locks are emptying simultaneously (Plate 3) and a lower pool el of 279. Three steady-state flow conditions were tested: land lock emptying, river lock emptying, and both locks emptying simultaneously. The magnitudes and directions were measured at 1, 6.3, and 14.8 ft above the channel invert (el 260). The velocities 1 ft above the invert were plotted directly, whereas the velocities measured 6.3 and 14.8 ft above the invert were taken to determine the magnitude and direction of the depth-averaged velocities. Initially, all tests were conducted with a river unit discharge of 57 cfs/ft. The direction and magnitude of velocities measured 1 ft above the river invert and the depth-averaged velocities resulting from the land lock emptying are shown in Plates 4 and 5, respectively. The velocities resulting from the river lock emptying are shown in Plates 6 and 7. Plates 8 and 9 show the velocity magnitudes and directions measured for steady flow from both locks emptying simultaneously.

8. Photos 1 and 2 are flow conditions near the outlet structure at the peak discharge during the land lock emptying and river lock emptying, respectively. The outlet structure has been sketched on the photos to orient the observer. Photo 3 shows the flow conditions at the maximum discharge (21,000 cfs) with both locks empty simultaneously. No adverse flow conditions were observed during lock emptying operations.

Type 1 Riprap

9. At this point in the testing program, there was concern regarding the riprap plan in the vicinity of the outlet structure. The molded cement used to represent the river invert was replaced with scaled riprap in the vicinity of the outlet structure (Figure 3). Tests were conducted to determine the stability of the type 1 riprap plan, which consisted of stones having a D_{50} of 20 in. placed from sta 30+46 (125 ft upstream of the outlet structure) to sta 35+66 (250 ft downstream of the outlet structure) and from the

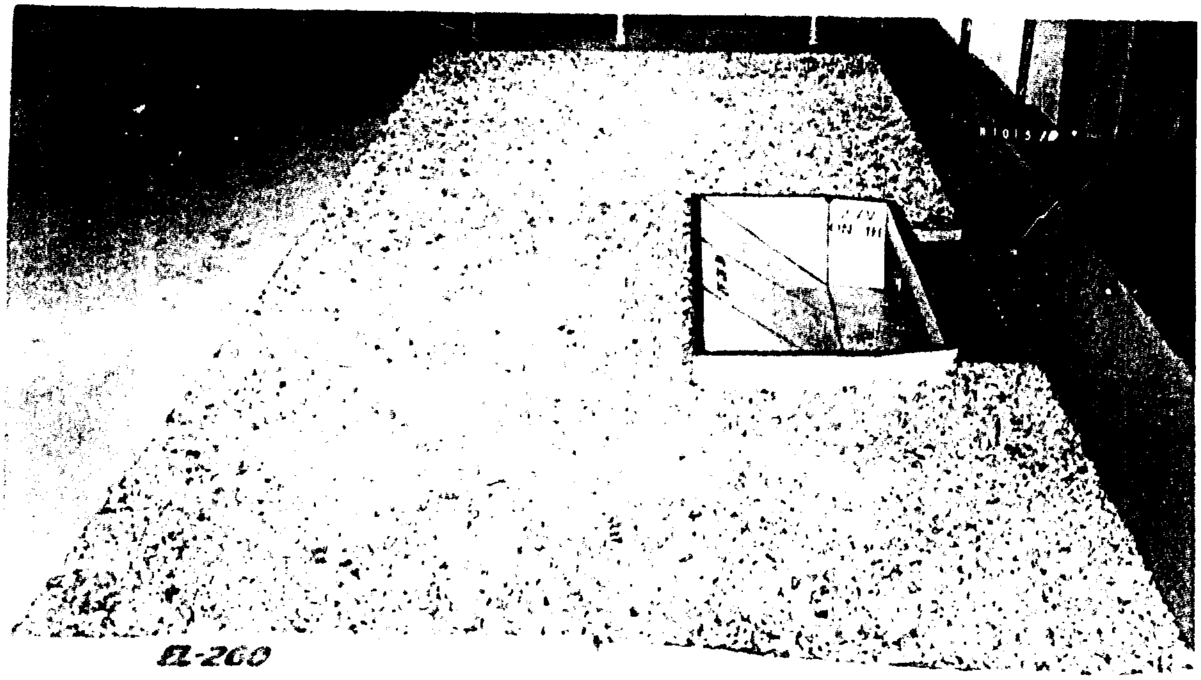


Figure 3. The type 1 design riprap plan

lock wall riverward 250 ft. The gradation of the type 1 riprap is shown in Plate 10. The conditions of these stability tests consisted of a river unit discharge of 57 cfs/ft, tailwater el 279, and steady maximum outlet discharge from the river lock, land lock, and/or both locks for 5 prototype hours. The tests revealed that the type 1 riprap plan was stable for each of these flow conditions.

10. Concurrent tests were being conducted in the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, on a physical model of the Olmsted Dam navigation pass gate.* Tests with the Olmsted navigation pass model determined the most severe flow condition for riprap along the lock wall: when the first 10 gates adjacent to the lock were open. The entrance configuration of the lock outlet model was modified to reproduce the flow conditions found in the Olmsted navigation pass model to be the most severe for riprap stability along the lock wall. Velocities in the vicinity of the

* W. G. Davis. "Olmsted Navigation Pass Gate, Ohio River; Hydraulic Model Investigation" (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

outlet structure resulting from these flow conditions (river unit discharge of 130 cfs/ft concentrated along the lock wall and tailwater el of 279) were measured. Velocities with the land lock emptying are shown in Plates 11 and 12, and with the river lock emptying in Plates 13 and 14. Steady flow velocities resulting from both locks emptying simultaneously are provided in Plates 15 and 16.

11. The type 1 design riprap plan was tested with steady flow through the outlet for 5 hr (prototype) for the three lock emptying conditions with a river unit discharge of 130 cfs/ft concentrated along the lock wall and tailwater el 279. After both locks had been discharging 10,500 cfs per lock for 5 hr (prototype), a few stones were displaced in an area about 15 to 25 ft riverward from the outlet structure. When both locks were discharging 10,500 cfs per lock, a jet was present near the surface of the riverflow. This high-velocity jet produced uplifting forces on the bed approximately 20 ft from the structure. This was an extreme test condition; however, it was felt that these tests needed to be conducted to determine riprap stability.

Type 2 Riprap

12. The type 1 design riprap plan was replaced with the type 2 design riprap plan, which consisted of stones having a D_{50} of 24 in. and a gradation as shown in Plate 17. The type 2 design riprap plan covered the same area as the type 1 riprap plan (from sta 30+46 to sta 35+66 and from the lock wall riverward 250 ft). This protection plan was also tested for 5 hr (prototype) with a discharge of 130 cfs/ft concentrated along the lock wall, a lower pool el of 279, and steady maximum discharges exiting both locks. Test results indicated that the type 2 design riprap plan was stable for these extreme flow conditions.

PART IV: SUMMARY AND RECOMMENDATIONS

13. The navigation locks at the proposed Olmsted project will consist of two 110- by 1,200-ft locks having a design lift of 21 ft. The locks' filling and emptying system consists of culverts from the land wall, the river wall, and the middle wall emptying into a single outlet structure located in the river. The Olmsted Lock design is unique in that the four culverts from the two locks all terminate in a common outlet structure. Observation of flow patterns in the vicinity of the outlet structure during emptying operations indicated that no adverse flow conditions resulted from the combining of the four culverts into one outlet structure.

14. Stability tests were conducted with the type 1 design riprap plan, which consisted of stones having a D_{50} of 20 in. placed from sta 30+46 to sta 35+66 and from the lock wall riverward 250 ft. This plan was tested for the three lock emptying conditions (steady flow through the land lock, the river lock, and both locks simultaneously) with a river unit discharge of 130 cfs/ft and a lower pool el of 279. With both locks discharging 10,500 cfs per lock for 5 hr (prototype), a few stones were displaced in an area about 15 to 25 ft riverward from the outlet structure. With this condition, the flow from the outlet produced a jet near the surface of the riverflow. This high-velocity jet produced uplifting forces on the bed approximately 20 ft from the structure.

15. The type 2 design riprap plan (stones having a D_{50} of 24 in.) was found to be stable for the flow conditions described in paragraph 14. These stones were heavier than the uplifting forces created by the surface jet issuing from the outlet structure.

16. The outlet structure could perhaps be modified such that the lighter stone (D_{50} = 20 in.) would provide adequate scour protection. However, the original design outlet structure performed satisfactorily during lock emptying operations. Therefore, the original design lock outlet structure (Plates 1 and 2) and the type 2 design riprap plan are recommended for the prototype.

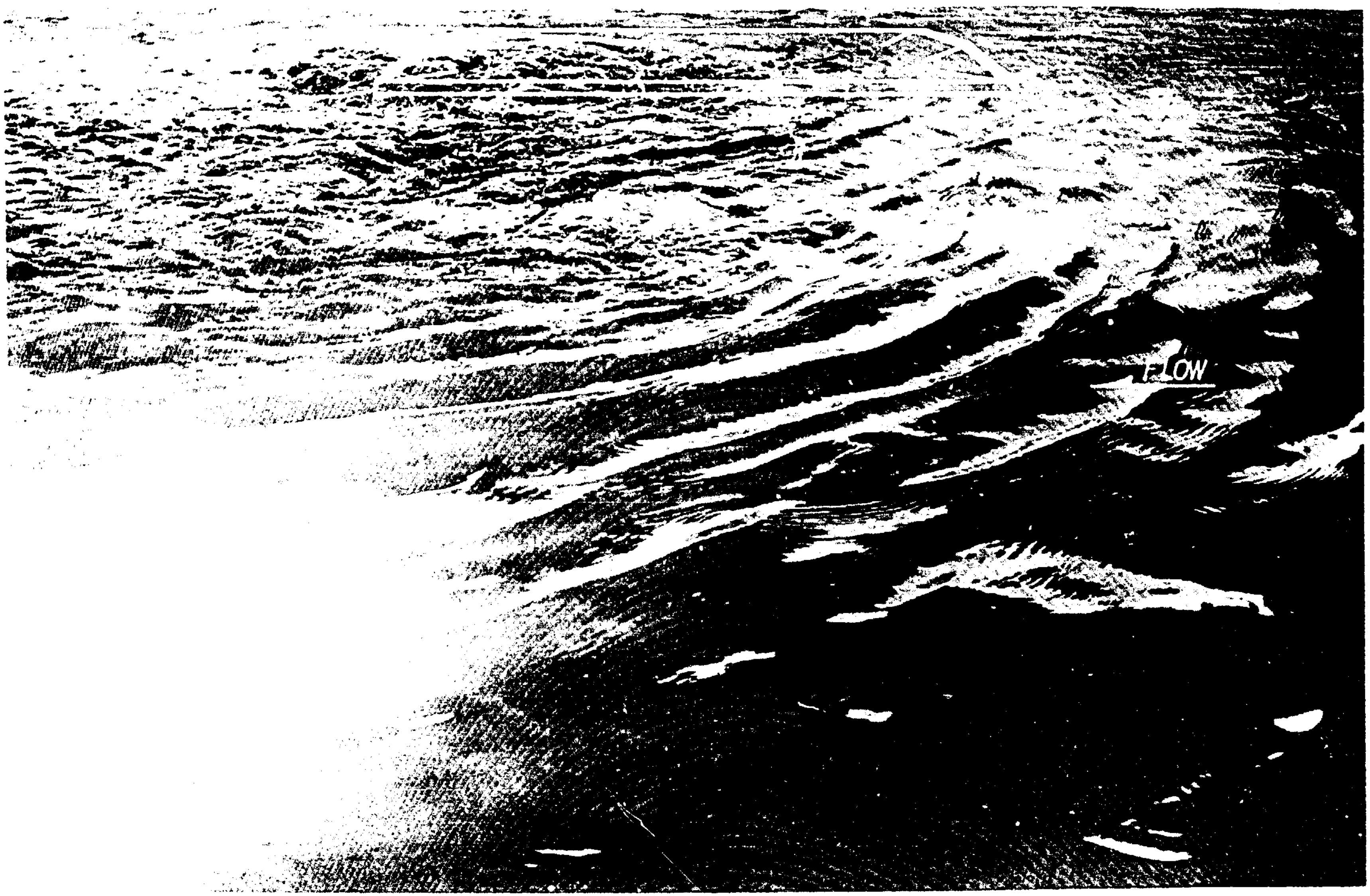


Photo 1. Flow conditions at peak outlet discharge with land lock emptying, 4-min valve operation, 21-ft lift, lower pool el 279

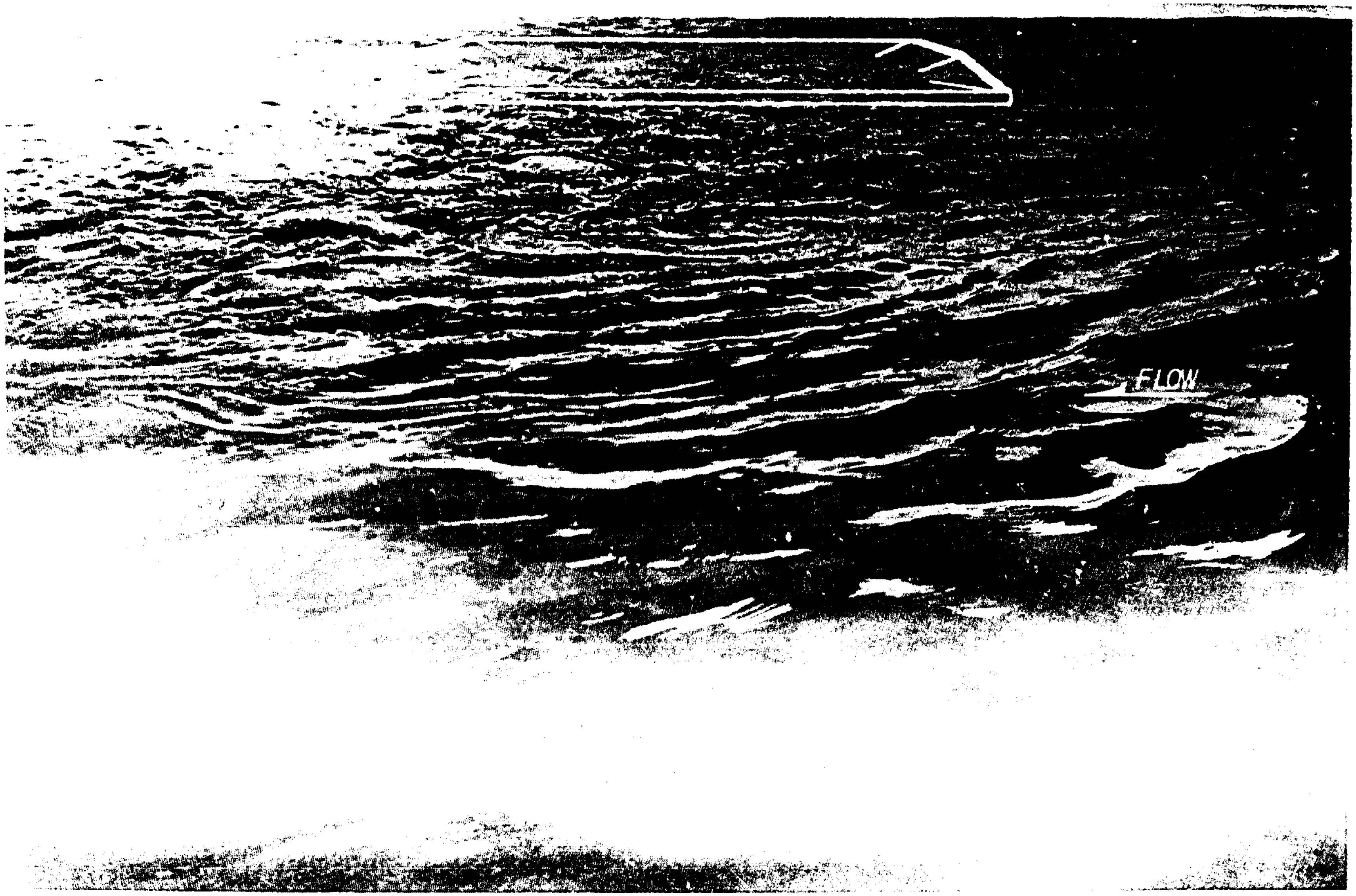


Photo 2. Flow conditions at peak outlet discharge with river lock emptying, 4-min valve operation, 21-ft lift, lower pool el 279

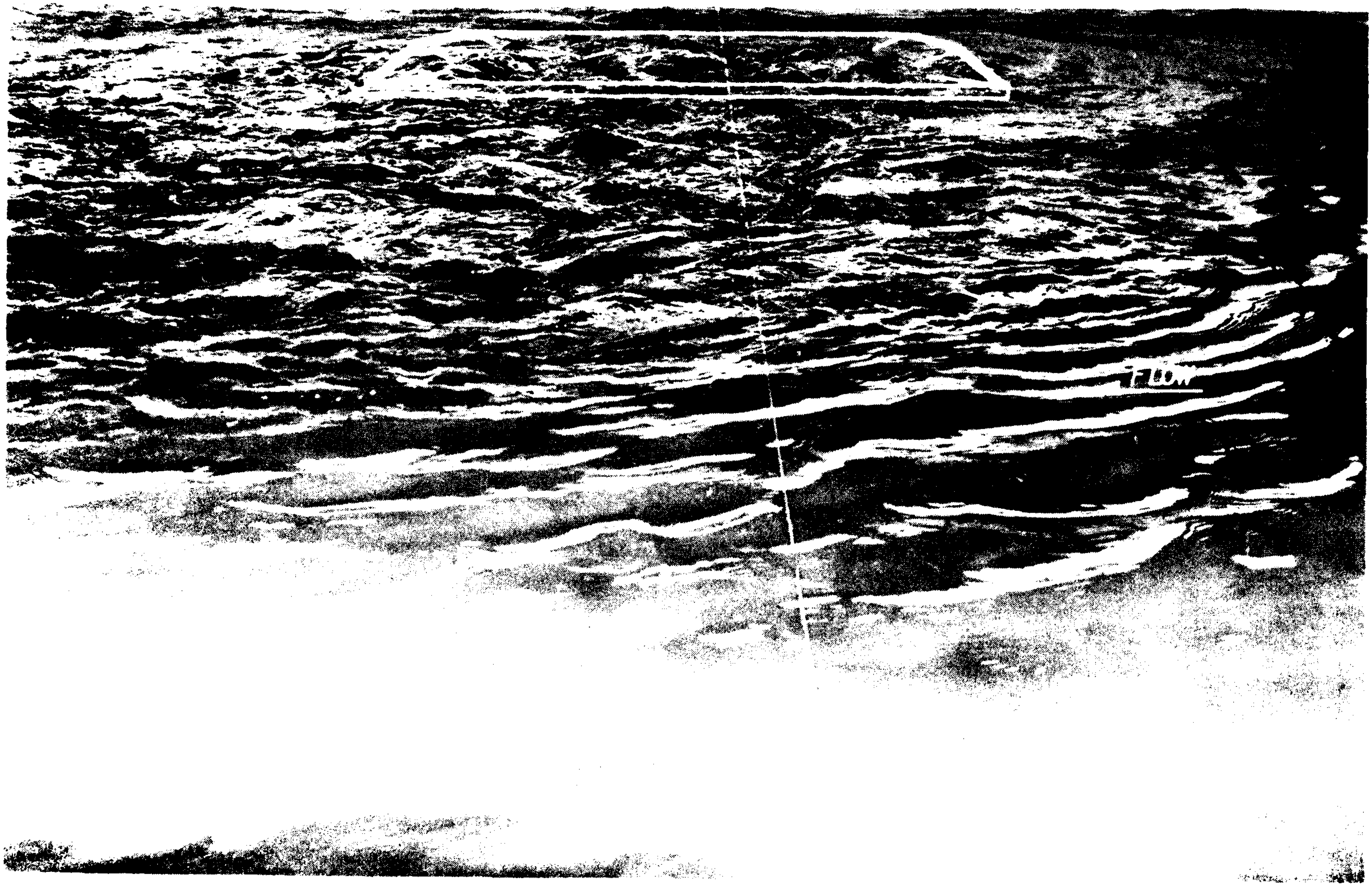
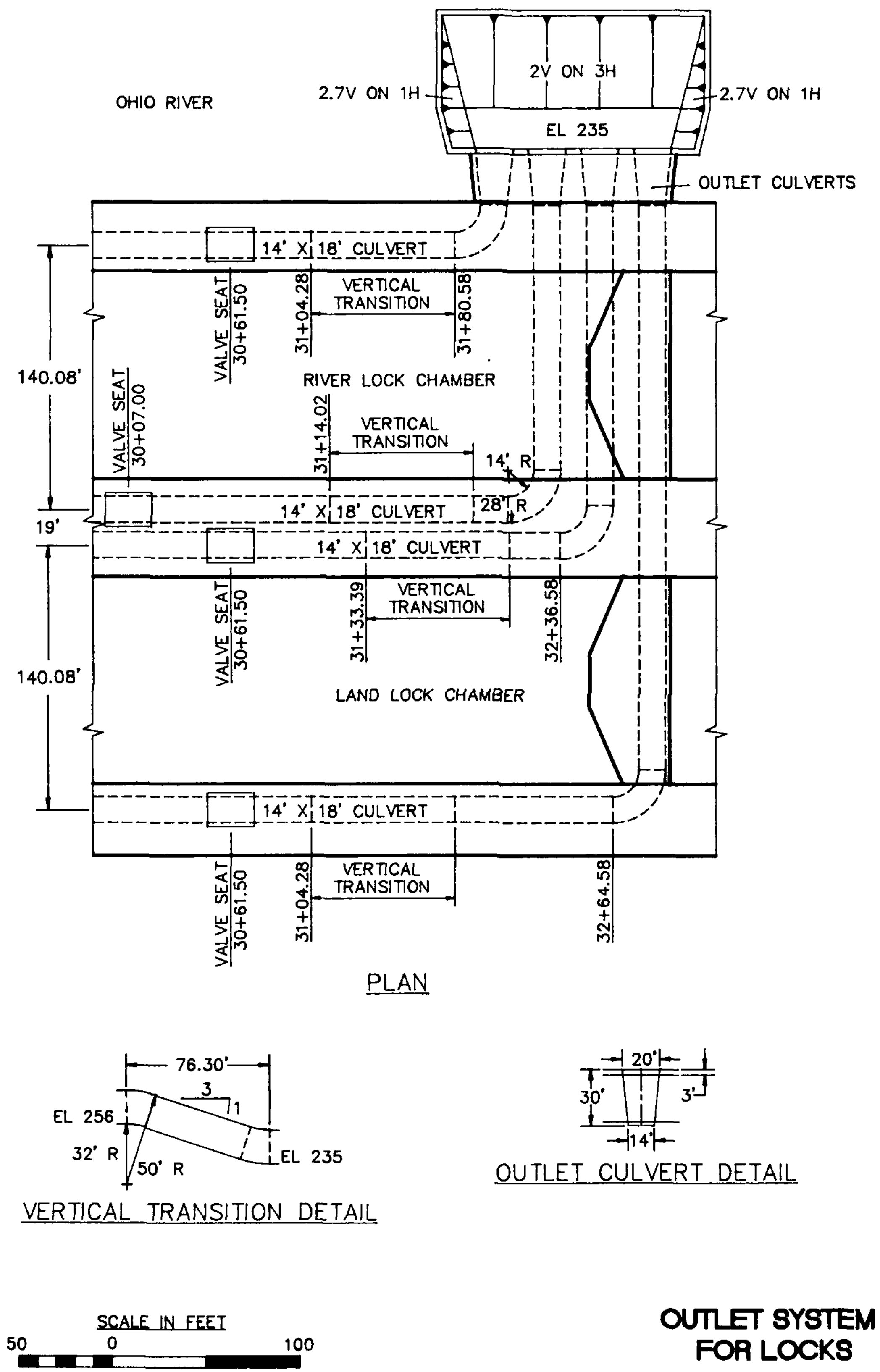
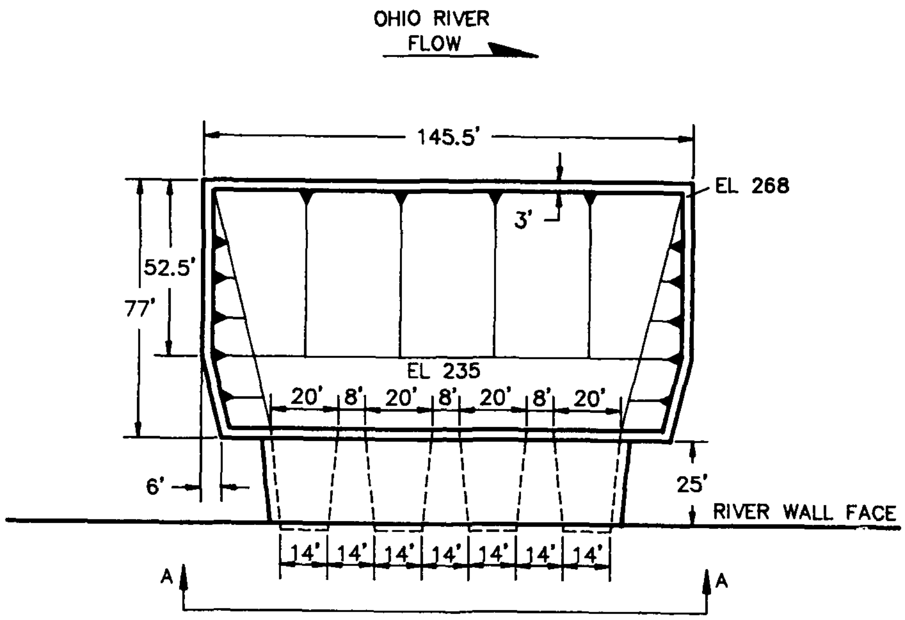


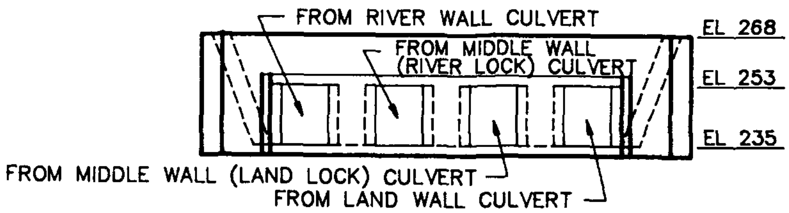
Photo 3. Flow conditions at peak outlet discharge with both locks emptying simultaneously, 4-min valve operation, 21-ft lift, lower pool el 279



OUTLET SYSTEM FOR LOCKS



PLAN



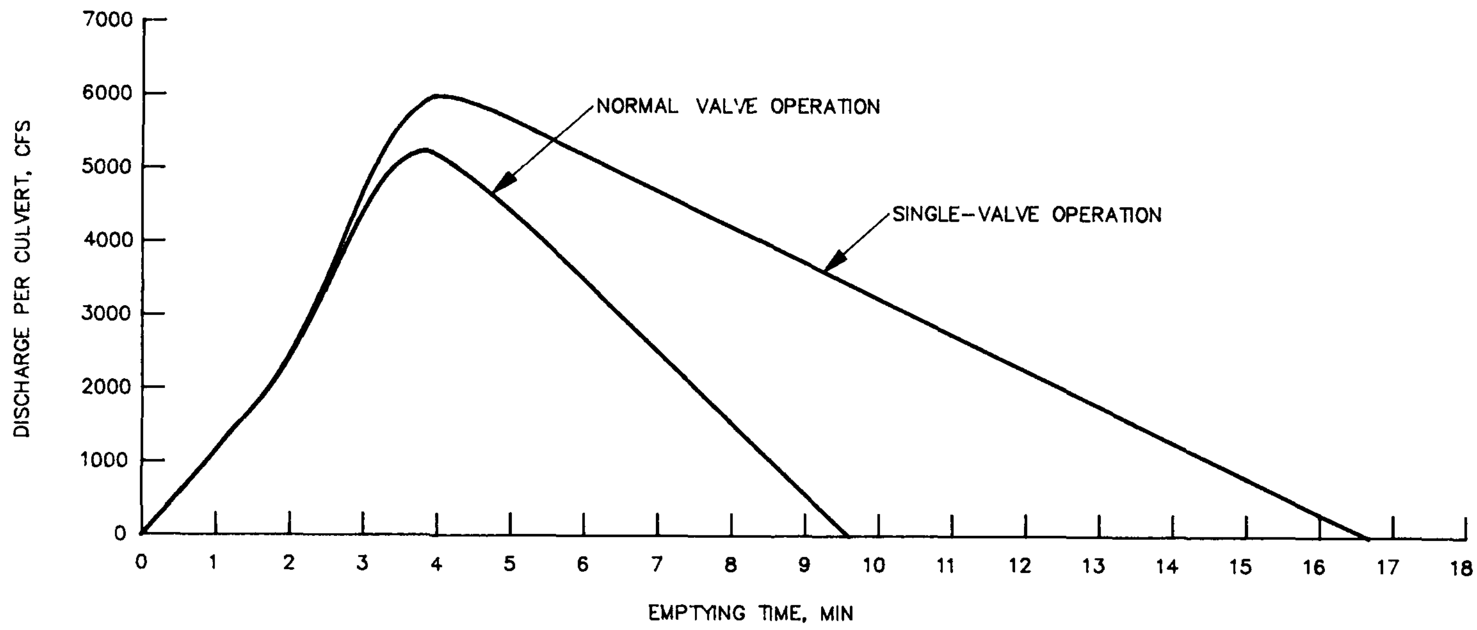
ELEVATION A-A

SCALE IN FEET

25 0 25 50

OUTLET BUCKET DETAILS

PLATE 2

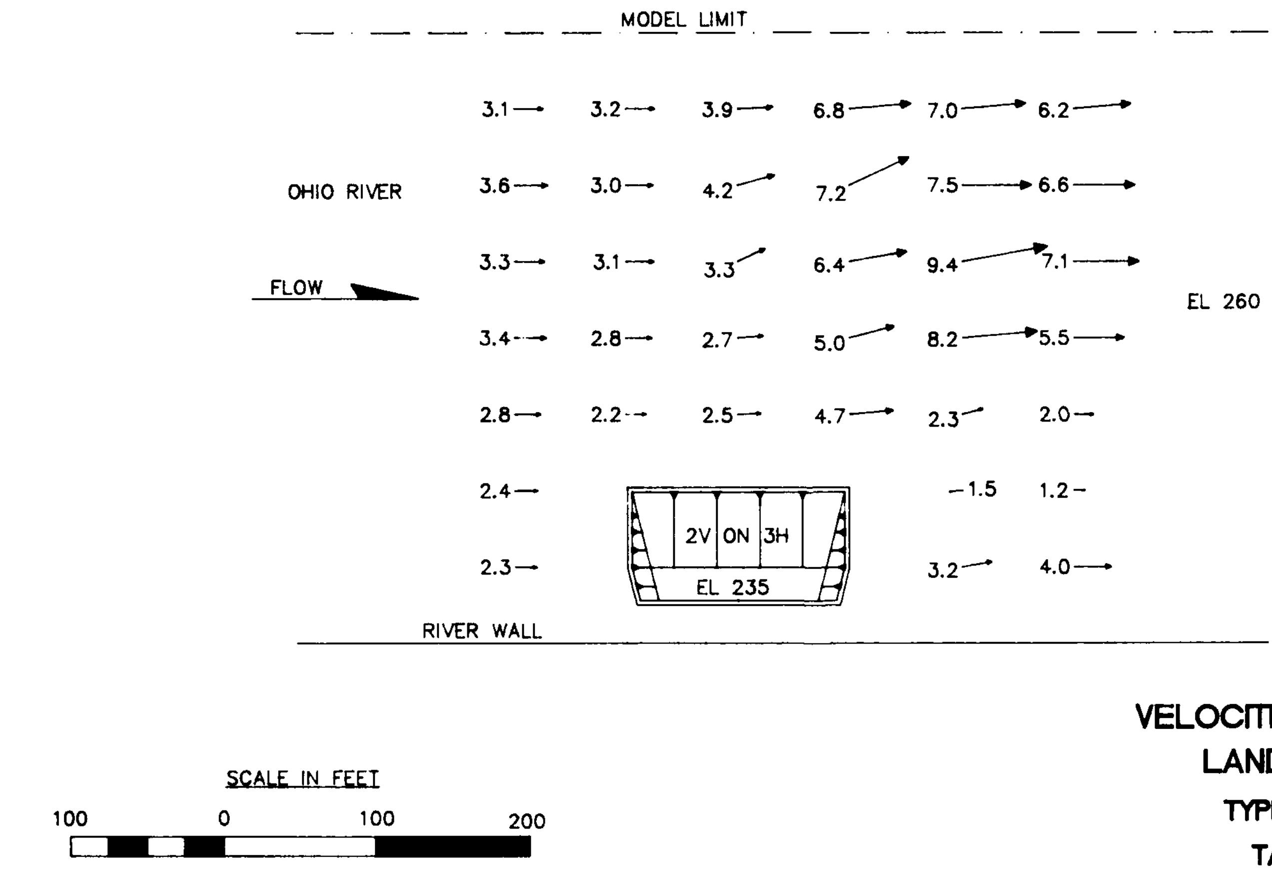


LOCK EMPTYING HYDROGRAPHS

UPPER POOL EL 300

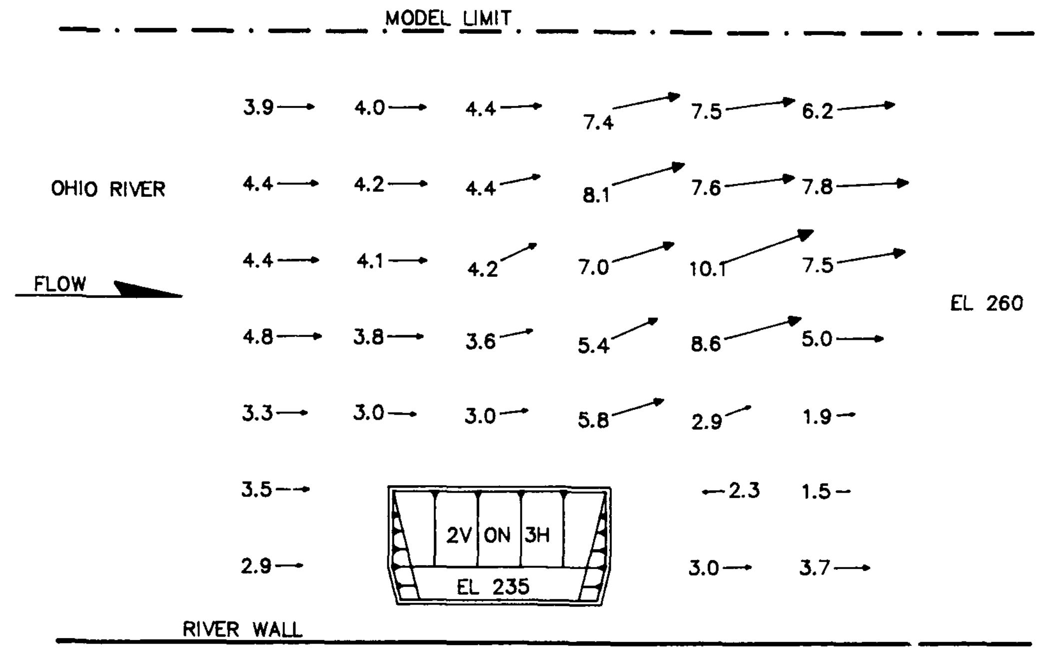
LOWER POOL EL 279

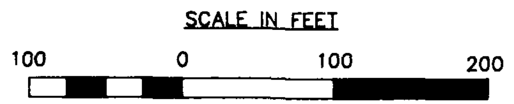
4-MIN VALVE OPERATIONS



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

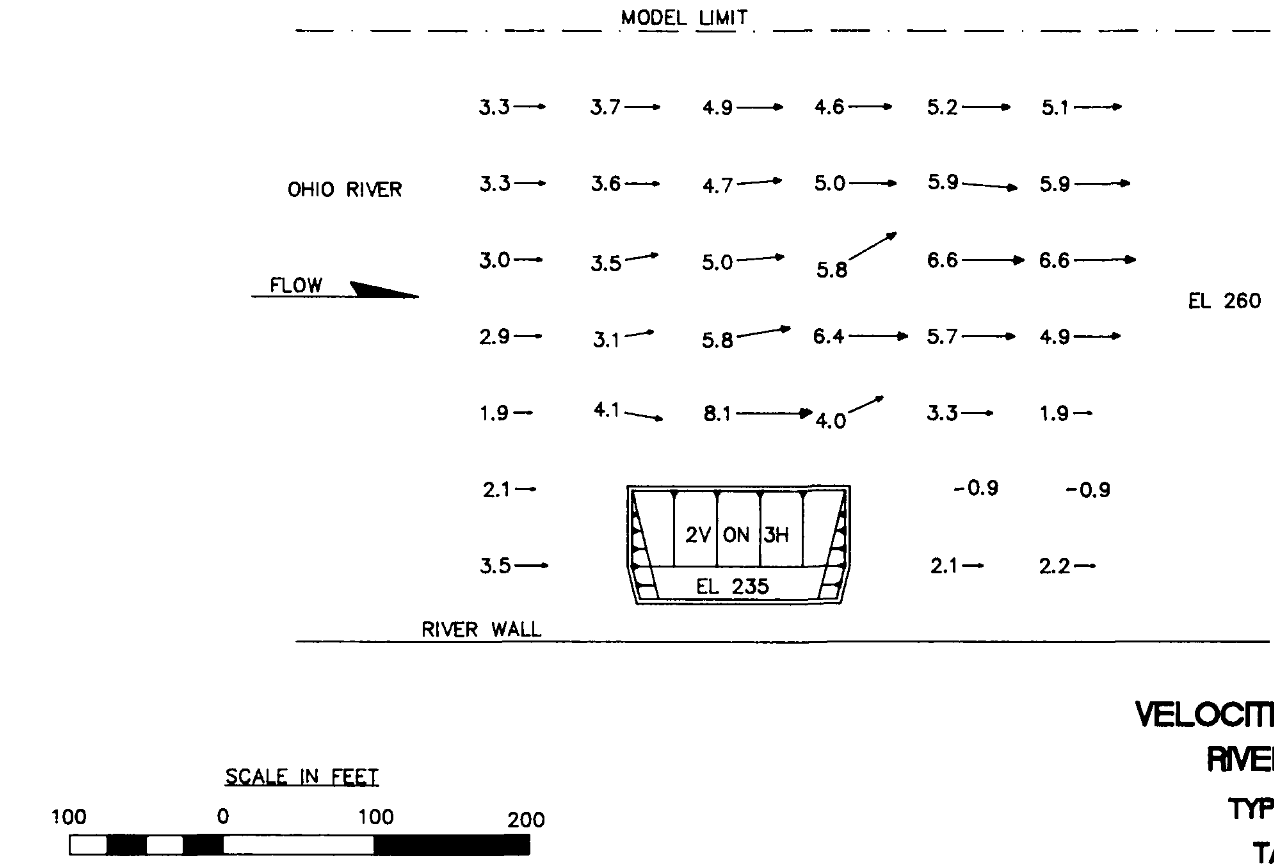
VELOCITIES 1 FT ABOVE INVERT
LAND LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
10,500 CFS THROUGH OUTLET





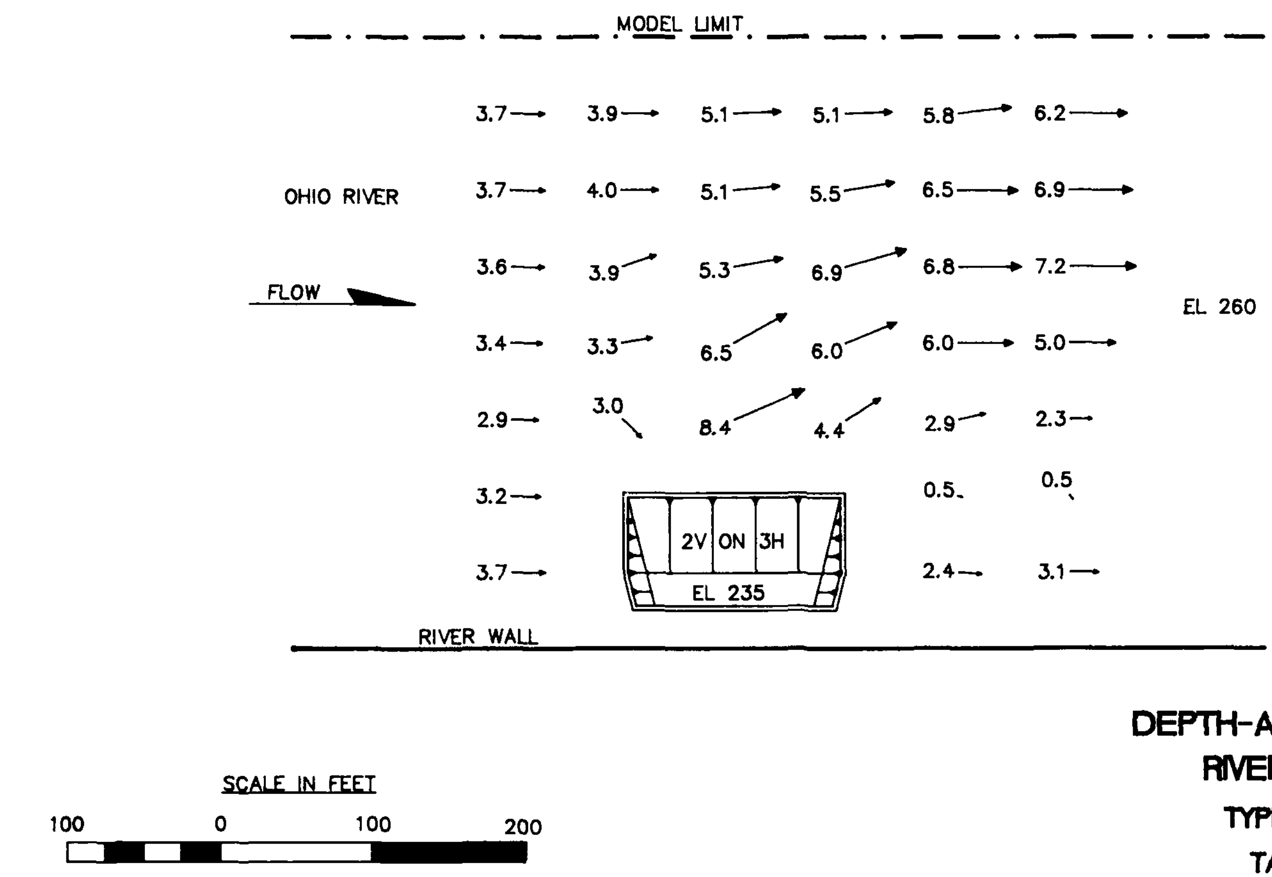
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

DEPTH-AVERAGED VELOCITIES
LAND LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
10,500 CFS THROUGH OUTLET



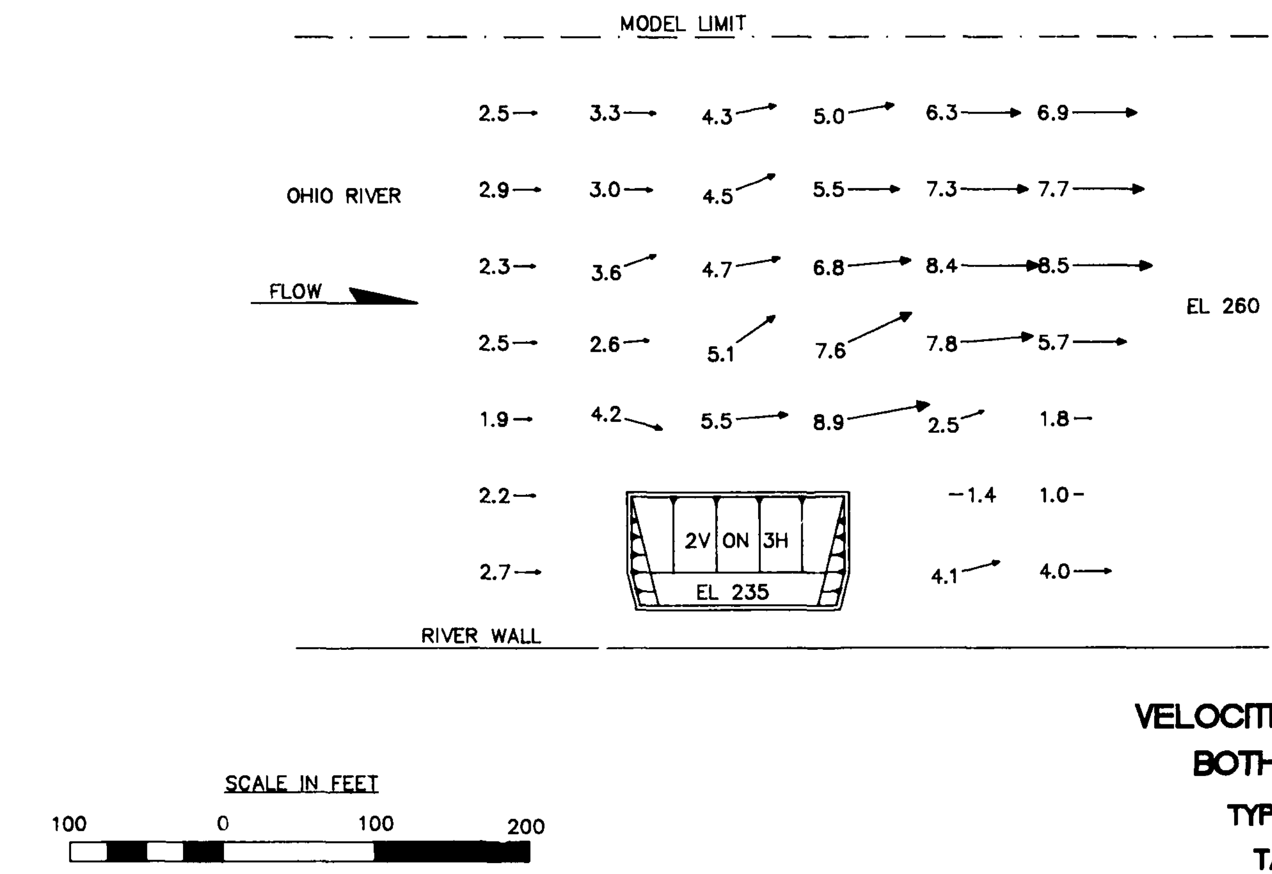
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

VELOCITIES 1 FT ABOVE INVERT
RIVER LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
10,500 CFS THROUGH OUTLET



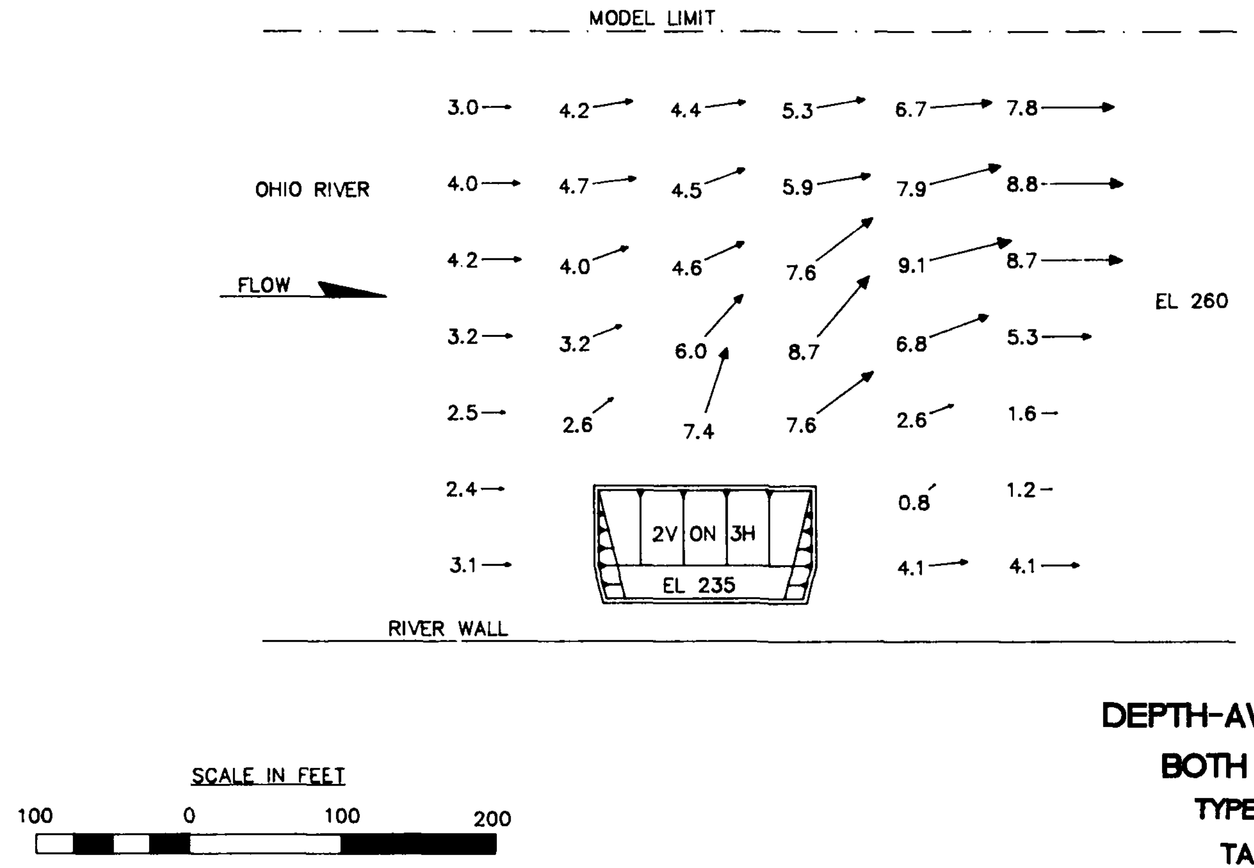
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

DEPTH-AVERAGED VELOCITIES
RIVER LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
10,500 CFS THROUGH OUTLET



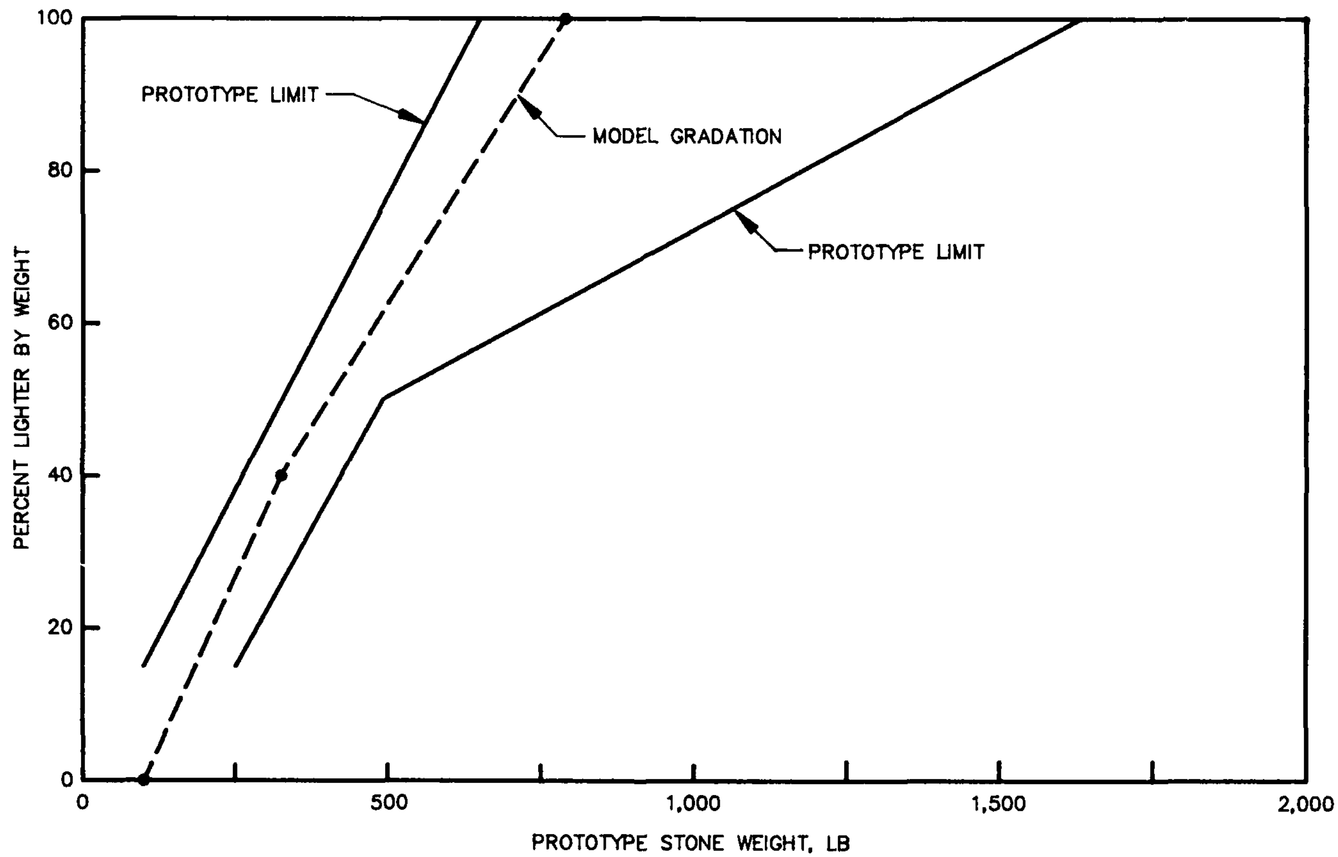
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

VELOCITIES 1 FT ABOVE INVERT
BOTH LOCKS EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
21,000 CFS THROUGH OUTLET



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

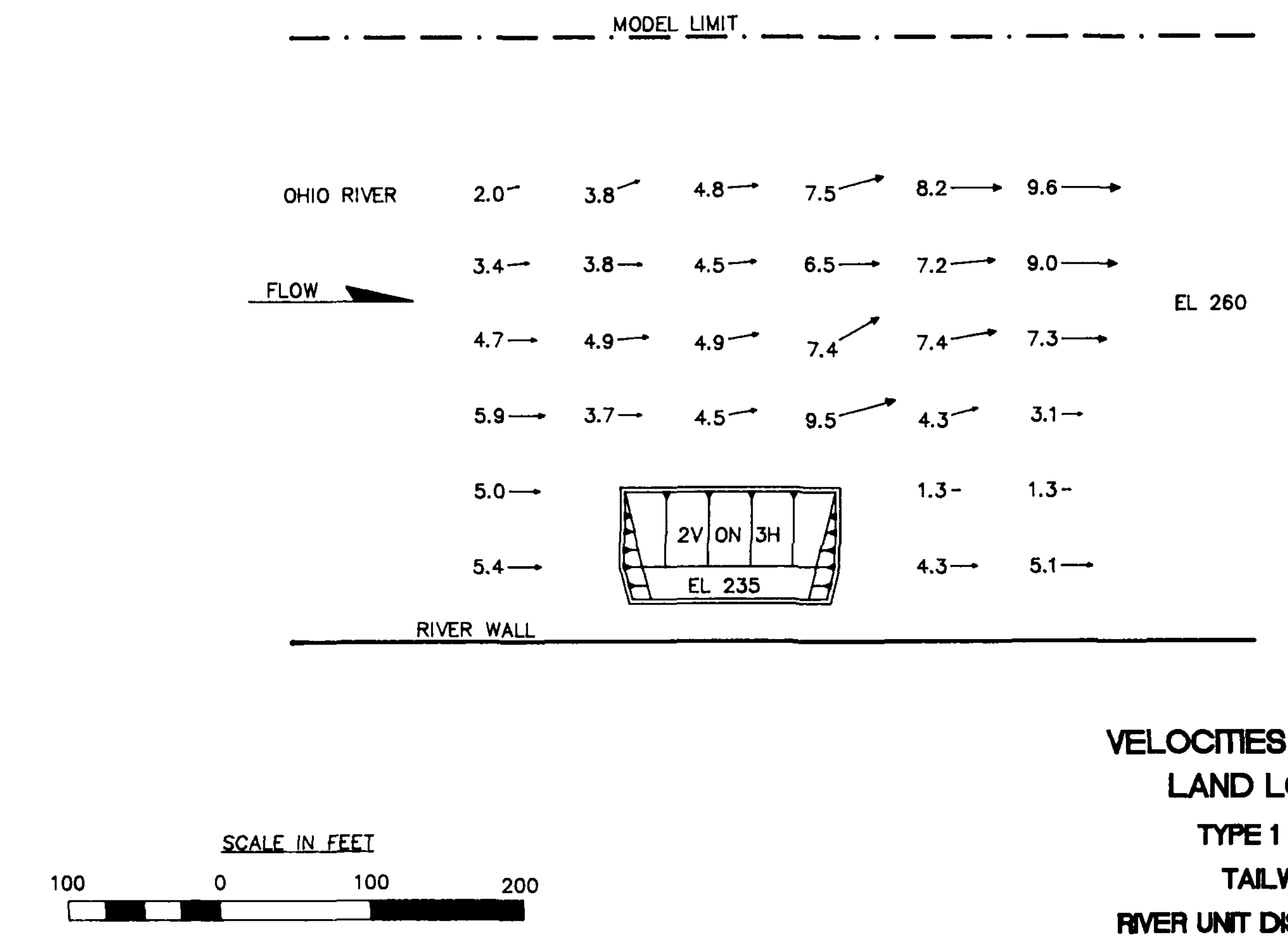
DEPTH-AVERAGED VELOCITIES
BOTH LOCKS EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 57 CFS/FT
21,000 CFS THROUGH OUTLET



TYPE 1 RIPRAP GRADATION

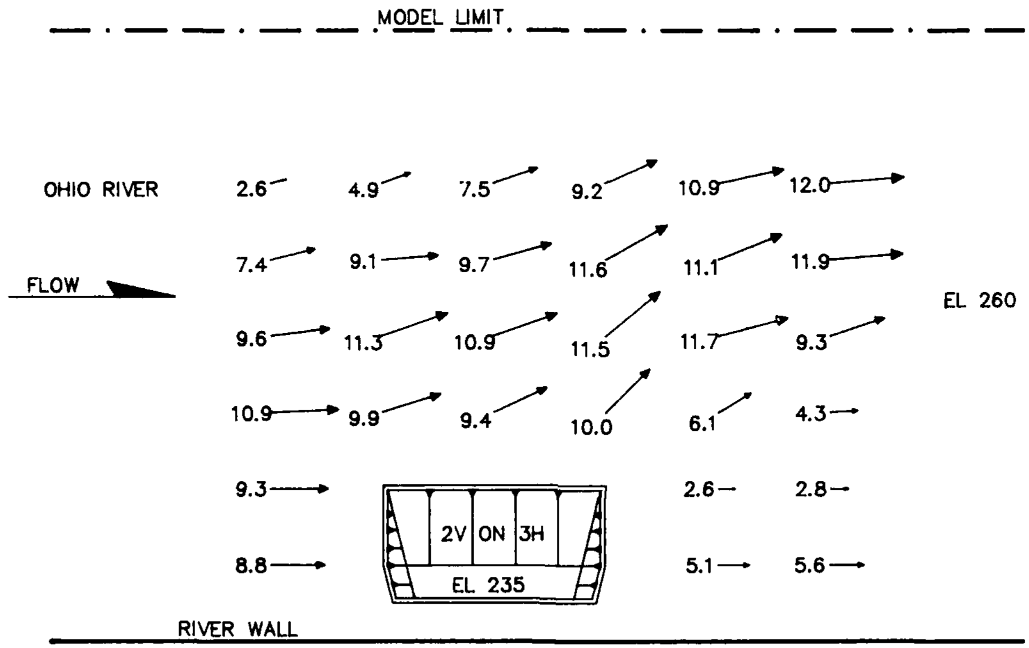
BLANKET THICKNESS = 48 in.

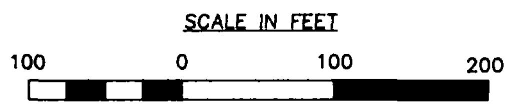
D_{50} = 20 in.



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

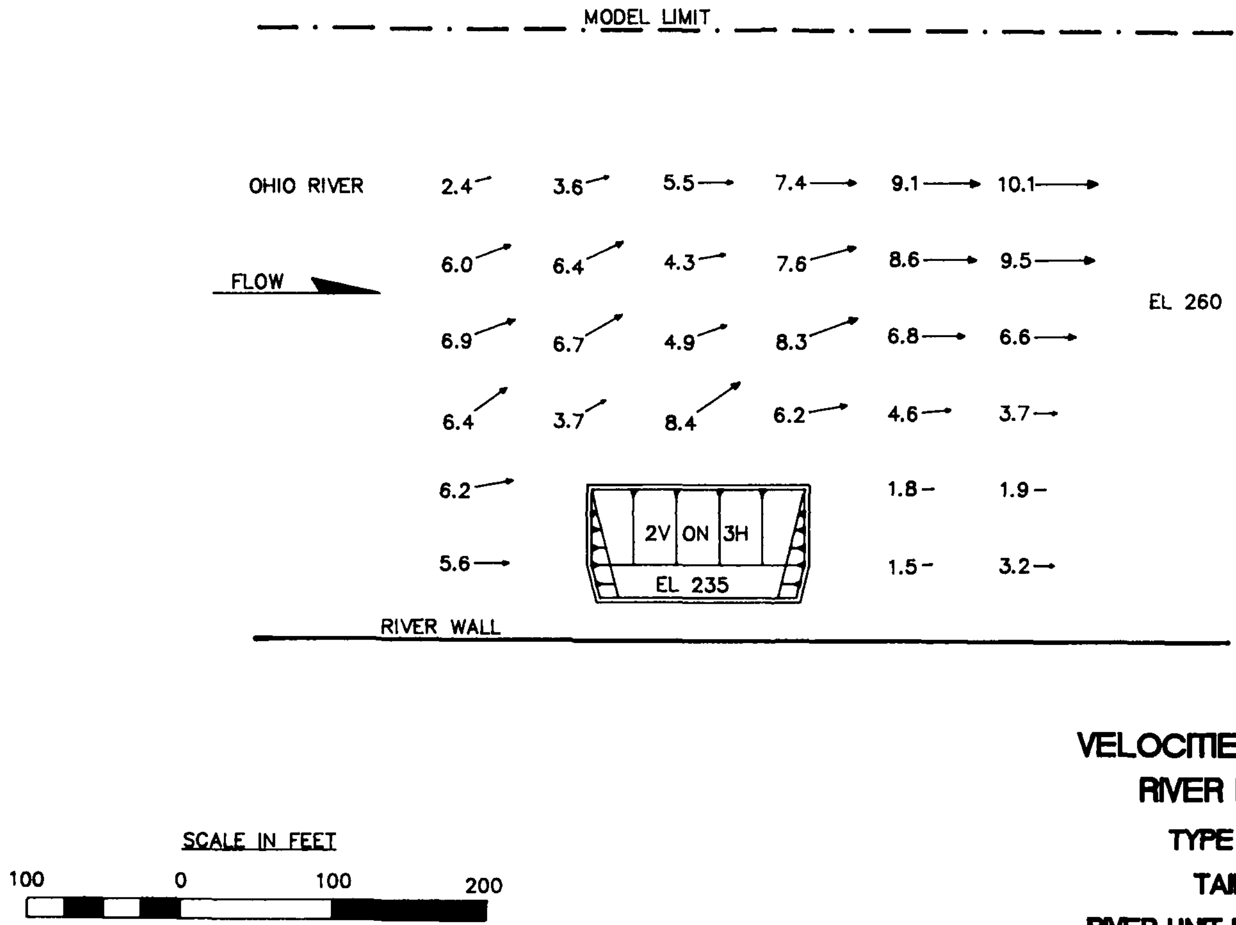
VELOCITIES 1 FT ABOVE INVERT
LAND LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
10,500 CFS THROUGH OUTLET





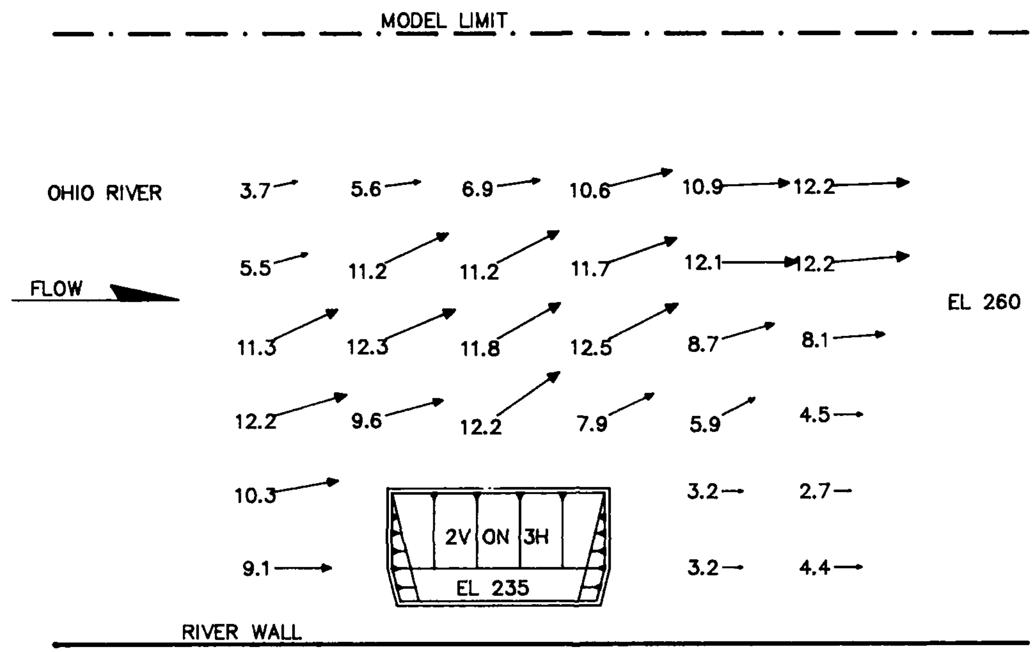
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

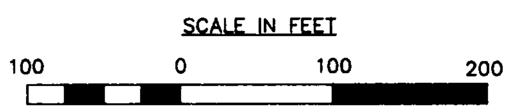
DEPTH-AVERAGED VELOCITIES
LAND LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
10,500 CFS THROUGH OUTLET



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

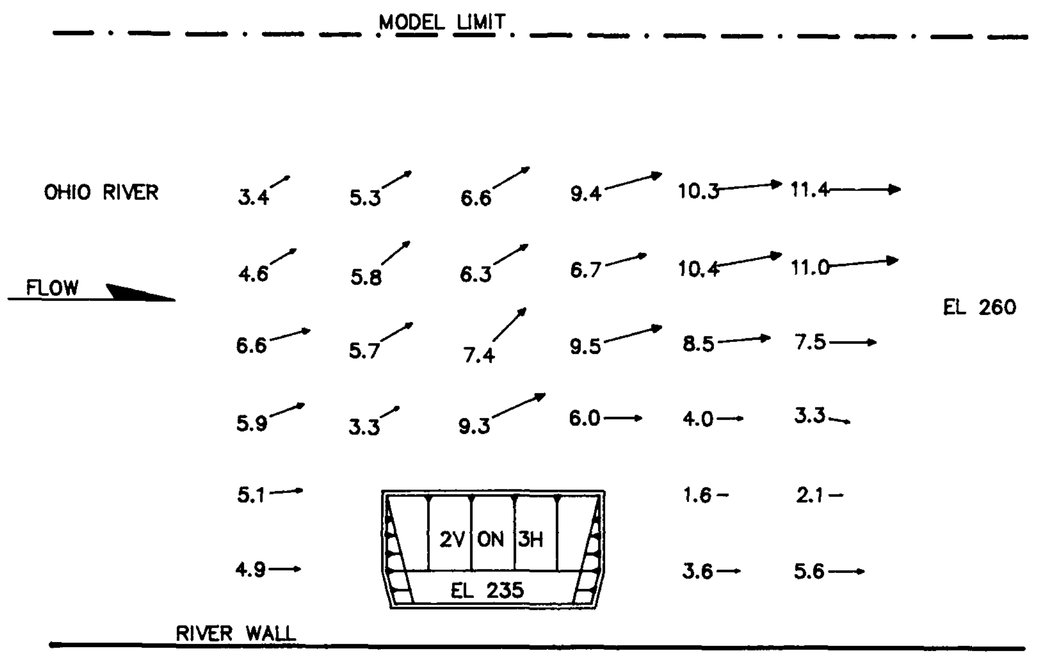
VELOCITIES 1 FT ABOVE INVERT
RIVER LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
10,500 CFS THROUGH OUTLET



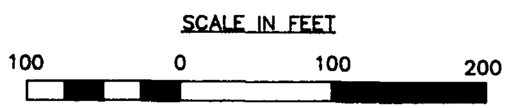


NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

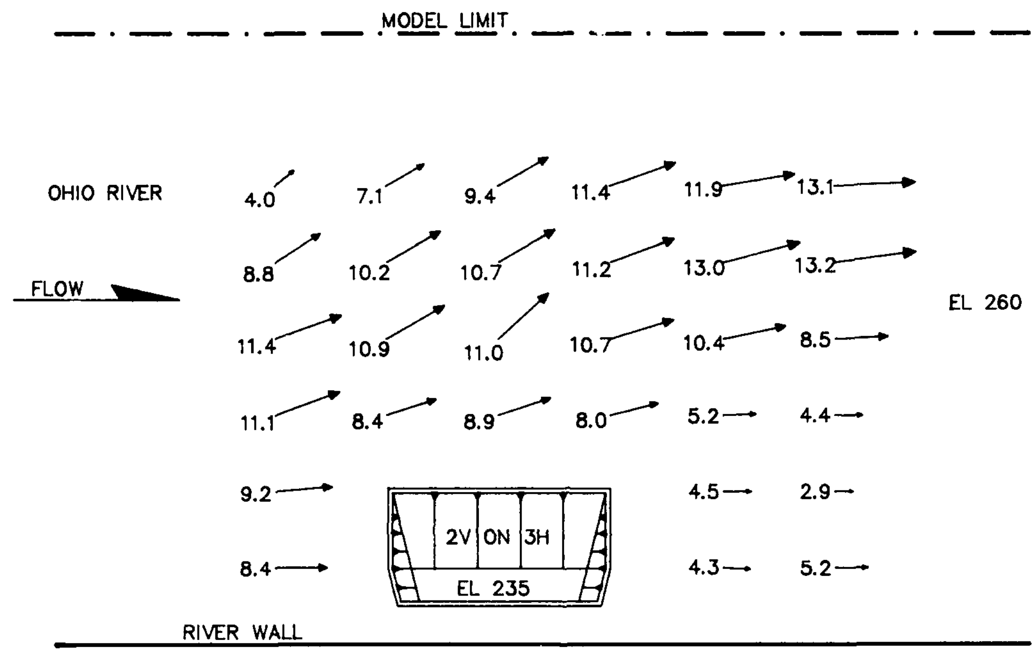
DEPTH-AVERAGED VELOCITIES
RIVER LOCK EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
10,500 CFS THROUGH OUTLET



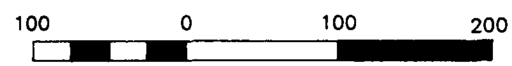
VELOCITIES 1 FT ABOVE INVERT
BOTH LOCKS EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
21,000 CFS THROUGH OUTLET



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

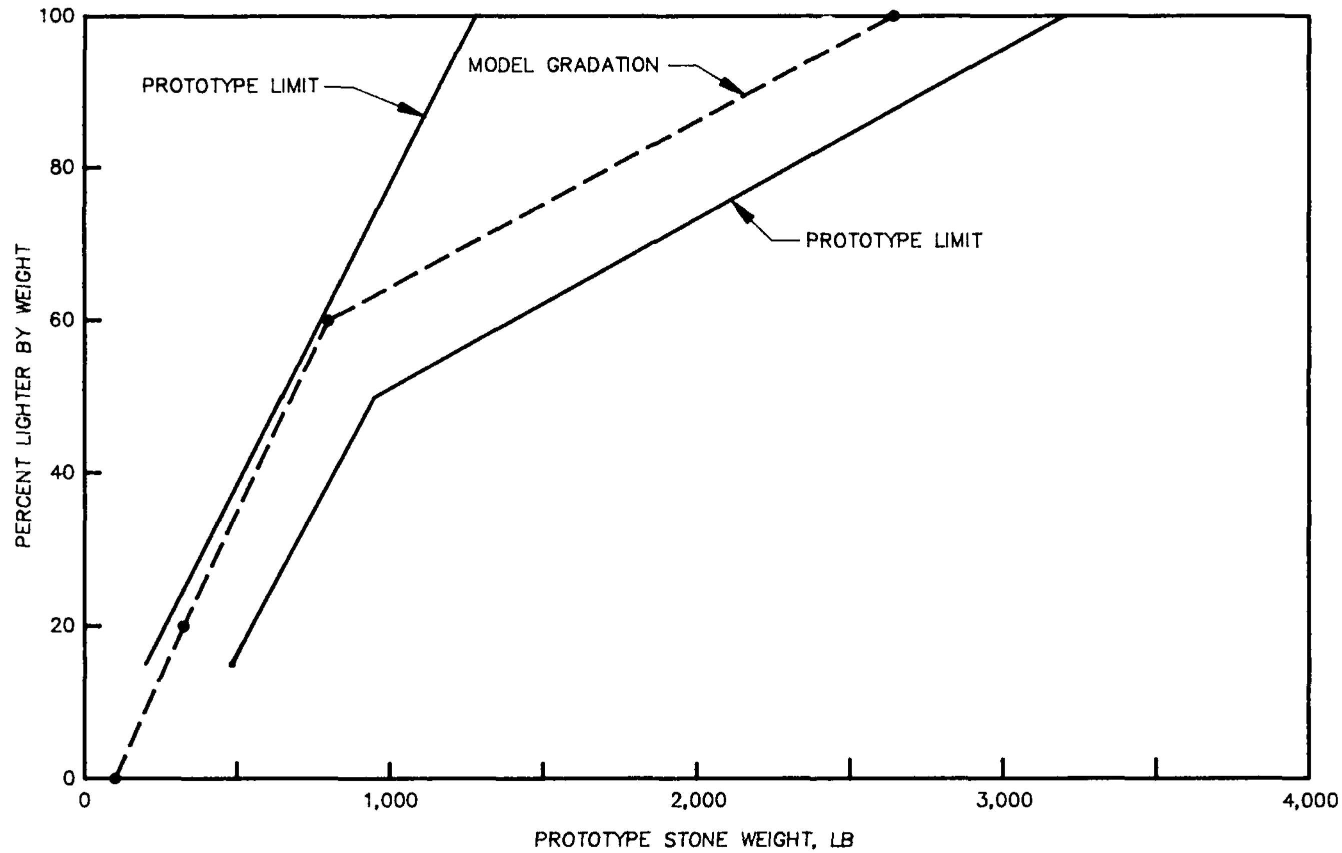


SCALE IN FEET



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

DEPTH-AVERAGED VELOCITIES
BOTH LOCKS EMPTYING
TYPE 1 DESIGN OUTLET
TAILWATER EL 279
RIVER UNIT DISCHARGE 130 CFS/FT
(CONCENTRATED ALONG LOCK WALL)
21,000 CFS THROUGH OUTLET



TYPE 2 RIPRAP GRADATION

BLANKET THICKNESS = 60 in.

D_{50} = 24 in.

Waterways Experiment Station Cataloging-in-Publication Data

Stockstill, Richard L.
Olmsted Lock outlet, Ohio River : hydraulic model investigation / by Richard L. Stockstill ; prepared for US Army Engineer District, Louisville.
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